Impulse Pendulum with Adjustable Pivot Point for Measuring Coupling Coefficient

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Abstract. An impulse pendulum with significantly increased sensitivity compared to its predecessor is described. The problems associated with its predecessor are discussed and other pendulum designs are also presented. The design approach for the new pendulum is then presented along with the current mechanical design and photographs of the finished pendulum. The pendulum's performance is presented compared to its predecessor. Finally, other embodiments of the approach are presented.

INTRODUCTION

The laser lightcraft is propelled by an expanding shock wave created by the ionization of air via a focused high-energy laser. The laser induced shock wave produces forces on the craft which can be resolved into axial, side, and pitching moments. The axial forces have typically been measured by mounting the lightcraft to a pendulum and measuring the angular displacement produced by a single pulse. Libeau, et al[1], have measured the side force and pitching moments via an Angular Impulse Measurement Device, or AIMD. In our work, we have typically neglected the pitching moments since the craft is spun at fairly high angular velocities (>3000rpm). However, it is desirable to use the same instrumentation for measuring the axial and side forces due to the amount of setup time required both for the device itself as well as the data acquisition system.

In the past, combinations of the side force and axial force measurements have been hampered by the sensitivity of the pendulum and the fact that the side forces are typically 1/3 those of the axial forces. Pendulum sensitivity is a direct function of the amount of mass hanging on the pendulum but in order to measure the side force, a 90-degree adapter must be used so that the craft's centerline is parallel with the pendulum's rotational axis. This allows the structure of the pendulum to absorb the axial thrust and respond only to the side forces acting on the craft.

In this paper, we present the self-defeating properties of the standard pendulum, the desired solution, an embodiment of that solution, and the performance data which shows the marked improvement.

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14. ABSTRACT
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THE STANDARD PENDULUM

The standard impulse pendulum assembly consists of two support posts, between which hangs the pendulum. The pendulum's shaft is supported by two non-sealed ball-bearings. A Rotary Voltage Displacement Transducer (RVDT) is connected to the shaft in order to record the angular displacement of the pendulum. The RVDT was manufactured by Schaevitz and is model number R30D, Serial # 7647. The standard pendulum is shown in Figure 1. No lightcraft is attached to the pendulum but a steel counterweight is attached that serves to balance the torque created by the lightcraft's mass and allow the pendulum to hang exactly vertical. This is desirable since it removes any error due to angular misalignment. The standard pendulum torque balancing force diagram is shown in Figure 2. The mass and the distance, d, of the counterweight can be set to optimize the pendulum's sensitivity. A small counterweight mass, m, is optimal since this reduces the total mass of the pendulum and thus allows a larger displacement for the same impulse from the lightcraft. However, the smaller mass must be placed at a greater distance, d, from the centerline of the pendulum in order to balance the torque created by the lightcraft's mass. Larger distances tend to produce undesirable harmonic oscillations in the pendulum structure that could adversely affect the accuracy of the measurement.

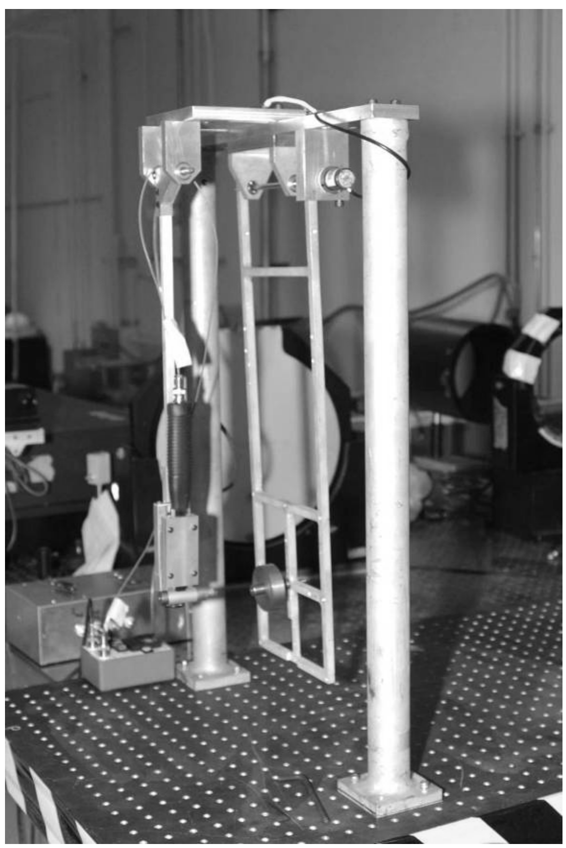

Figure 1. Standard Pendulum with counterweight attached. Also visible is the calibration hammer that provides the known force to which the RVDT is calibrated.

Also shown in Figure 1 is the calibration hammer, manufactured by PCB Piezotronics, model number PCB086C01 – Serial # 11610. The signal conditioner is model number PCB480E09. Once the pendulum is hanging exactly vertical, as measured by a standard contractor's grade torpedo level, the data acquisition system is readied to collect the RVDT data. The purpose of the calibration hammer is to deliver an impulse to the craft and simultaneously measure that impulse. This provides the basis for the calibration. The hammer's pivot point is set so that the tip of the hammer just barely touches the pendulum while delivering the known impact when it is exactly vertical. Thus, at rest, the hammer and pendulum hang exactly vertical and if the hammer were quickly drawn back, there is no discernable movement of the pendulum even though they are in contact at rest. A simple countdown is initiated in order to coordinate the start of the data collection and the hammer is drawn back. At t-minus one, the data collection is initiated and at zero, the hammer is released. The hammer bounces off the pendulum and is manually caught before it strikes it a second time. The data acquisition records three seconds of RVDT voltages and since the pendulum's period is approximately one second, at least 1.5 pendulum periods are captured for analysis.

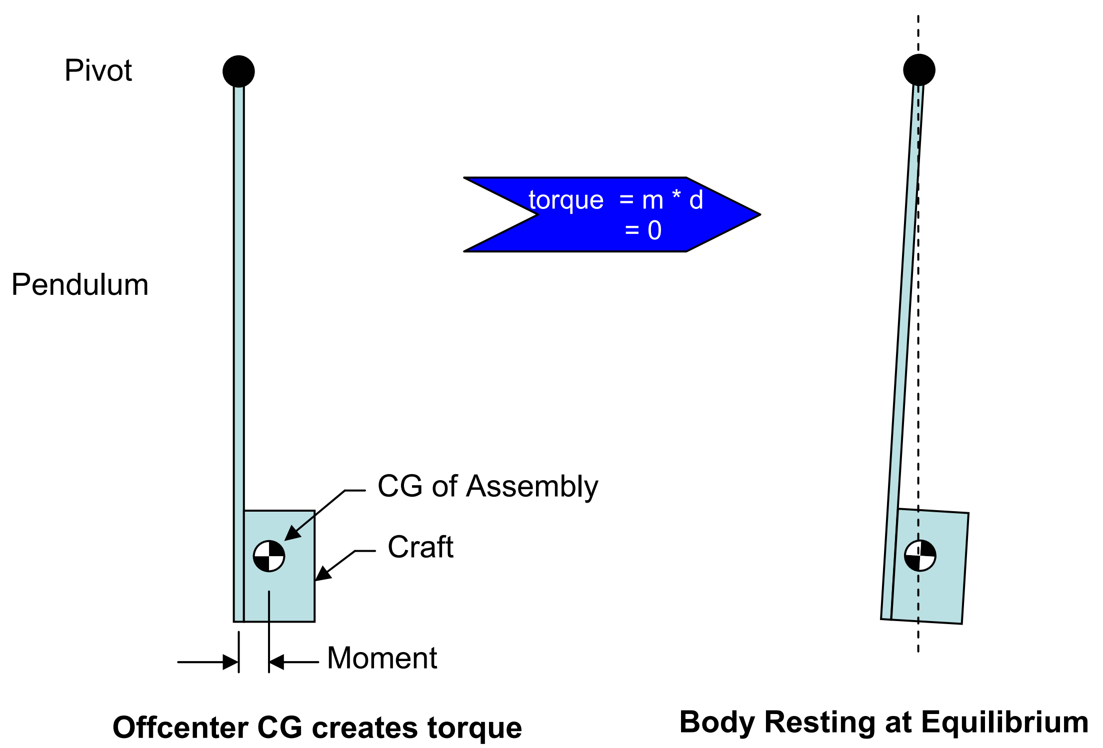

Figure 2. Force diagram for Standard Pendulum. A counterweight with mass, m, is mounted on the left side of the pendulum at some distance, d, from the centerline of the craft in order to balance the torque created by the lightcraft's mass and CG location.

The point of the calibration is to provide a range of impulses and corresponding RVDT voltages. Therefore, this procedure is repeated for various starting heights of the hammer in order to produce the curve shown in Figure 2.

The data acquisition system records the oscillations of the pendulum corresponding to a particular impulse level. The RVDT voltages can be somewhat noisy and are therefore filtered to remove the majority of high frequency noise that is present. The maximum of the signal is determined and plotted with respect to hammer voltage as shown in Figure 3. The results of a linear fit provide a direct conversion factor from RVDT volts to hammer volts which, in turn can be converted to impulse from the hammer manufacturer's calibration factor of 50mV/lbf.

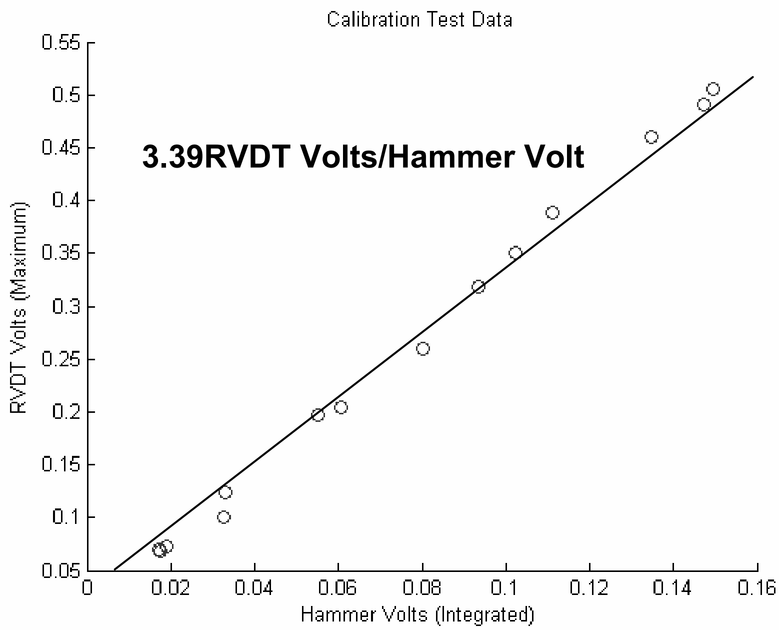

Figure 3. Axial force RVDT calibration results with the Standard Pendulum and model #200-23 craft.

THE PIVOT-BALANCED PENDULUM

The major drawback to the Standard Pendulum is its insensitivity when measuring the side force on a lightcraft model. In order to measure the side force, the craft is mounted to the pendulum using a 90-degree adapter which allows the pendulum to be displaced as a result of any side forces acting on the craft. The axial forces are absorbed within the structure so that very little or no pendulum displacement is registered. Due to the addition of the 90-degree adapter, the entire pendulum assembly must be rotated 90-degrees so that the underside of the craft is still illuminated by the PLVTS laser. The pendulum displacement therefore occurs orthogonal to the beam.

The 90-degree adapter is machined from a solid billet of 6061-T6 aluminum and is quite heavy in comparison to the craft. The side forces are typically 1/3 that of the axial forces and therefore, combined with the additional weight of the 90-degree adapter, the pendulum displacement is much less when using the Standard Pendulum.

Placing additional weight on the pendulum in order to balance the additional weight of the 90-degree adapter is self-defeating.

Therefore, rather than using the approach of torque balancing, we have developed an improved technique in which the pendulum is brought into balance by adjusting it's pivot-point to coincide with the lightcraft-pendulum's combined center of gravity. The Pivot-Balanced Pendulum's force diagram is shown in Figure 4. The proof of concept pendulum is shown in Figure 5.

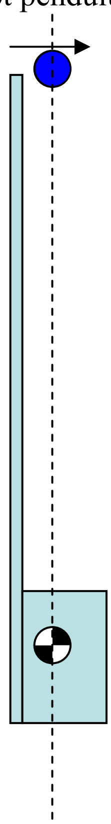

Figure 4. The pendulum's pivot point is moved so that the pivot point and craft/ pendulum CG both lie on a vertical line.

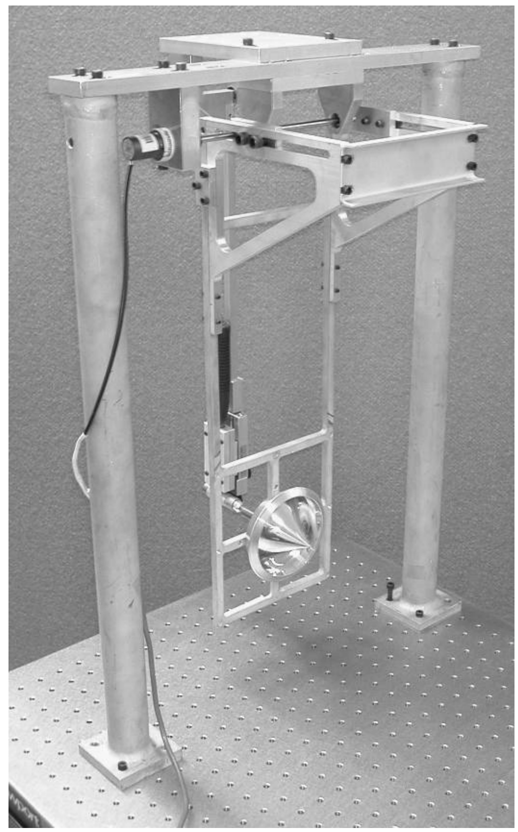

Figure 5. Pivot-Balanced Pendulum. Note the force hammer and 10cm Lightcraft.

Note the addition of a gantry in Figure 5. The width of the gantry determines the range of CG locations that can be handled by the pendulum and thus the gantry was designed to be wider than necessary for all anticipated lightcraft and associated apparatus. A narrower gantry would further reduce the overall mass and rotational inertia. See Figure 6.

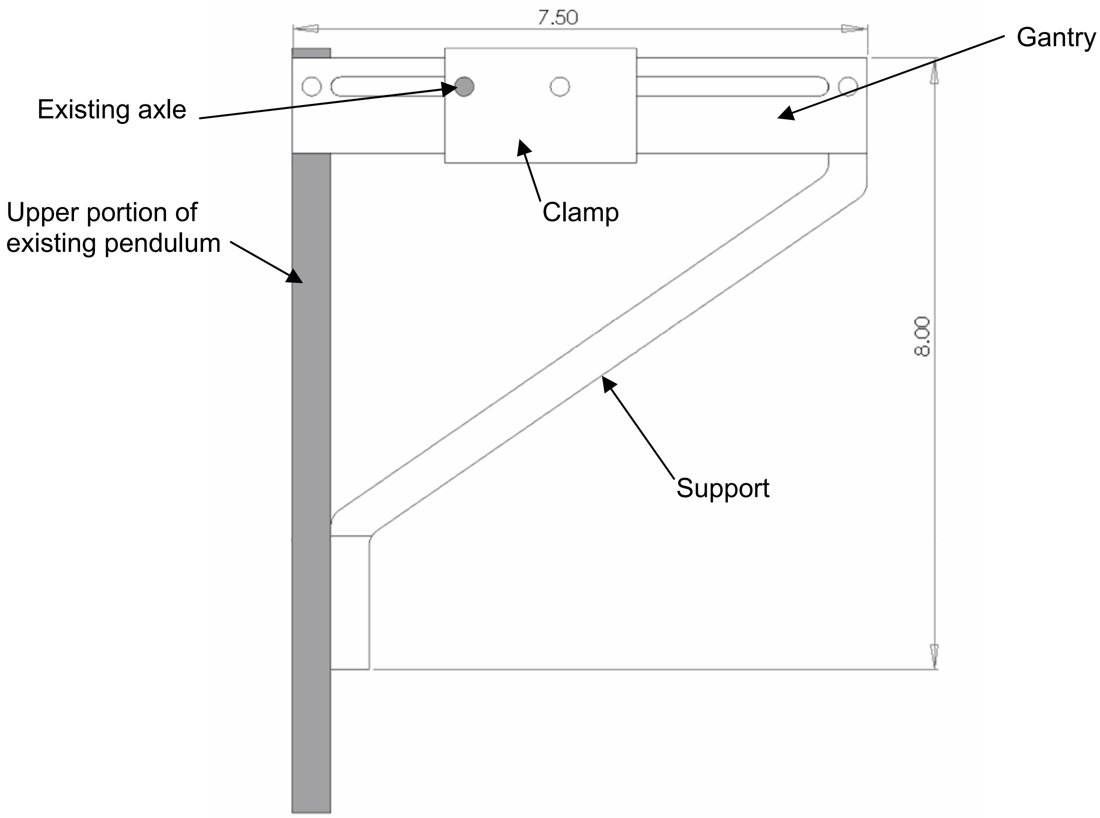

Figure 6. Pivot-Balanced Pendulum gantry details.

RESULTS

Collecting calibration data for a 23cm bench model lightcraft model #200-23 for axial force calibrations on both the Standard Pendulum, see Figure 3, as well as the Pivot-Balanced Pendulum, see Figure 7, resulted in a 48% increase in the maximum pendulum angular displacement. This modest increase was due solely to the removal of the counterweight. Performing a similar analysis for the side force measurement from the Standard Pendulum and the Pivot-Balanced Pendulum resulted in a 131% increase in pendulum sensitivity. The sole reason for the higher comparative sensitivity was due to the removal of the counterweight, which was much heavier than the counterweight for the axial force measurement.

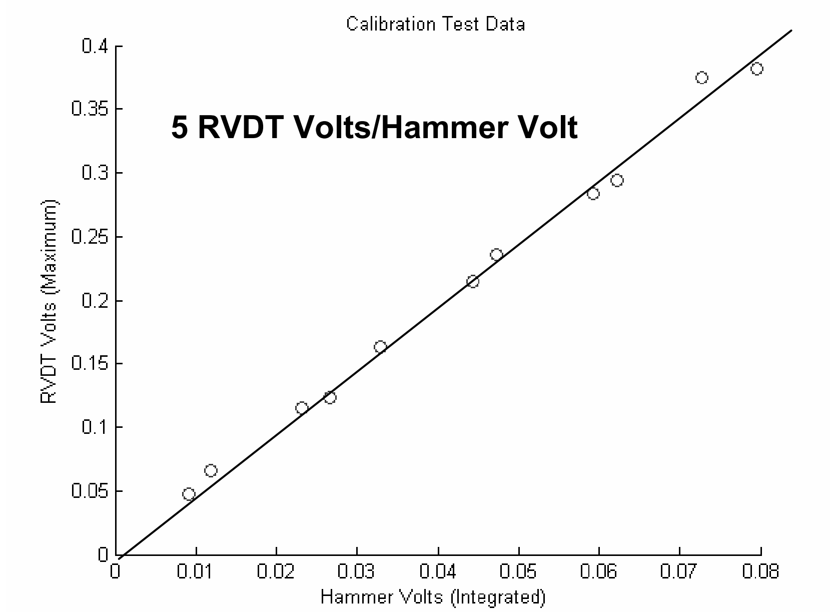

Figure 7. Axial force RVDT calibration results with the Pivot-Balanced Pendulum and model #200-23 craft. Compare to Figure 3.

CONCLUSIONS

We have shown that a Pivot-Balanced Pendulum is much more sensitive than the Standard Pendulum which uses a counterweight in order to balance the pendulum. When the pendulum is balanced, it hangs exactly vertical. The reason for this increase in sensitivity is due to the removal of the counterweight.

Future pendulum designs can be made more sensitive still, if particular attention is given to minimizing the rotational inertia of the Pivot-Balanced Pendulum while still providing the necessary structural integrity for a good, general purpose, laboratory instrument. These gains will be more modest than those demonstrated here since the largest gains in sensitivity are likely due to the removal of the counterweight.

REFERENCES

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